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(71) Applicant(s)
Mazda Motor Corporation

(Incorporated in Japan)

No 3-1 Shinchi, Fuchu-cho, Aki-gun, Hiroshima-ken, Japan

(72) Inventor(s)
Naotaka Hirami

(74) Agent and/or Address for Service
Gill Jennings & Every
Broadgate House, 7 Eldon Street, LONDON, EC2M 7LH, United Kingdom

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Electrical Review Vol.222 No.11,31 May-13 June 1989, C.Giona ta,"Adjusting to Self-tuning" pp.16-18.

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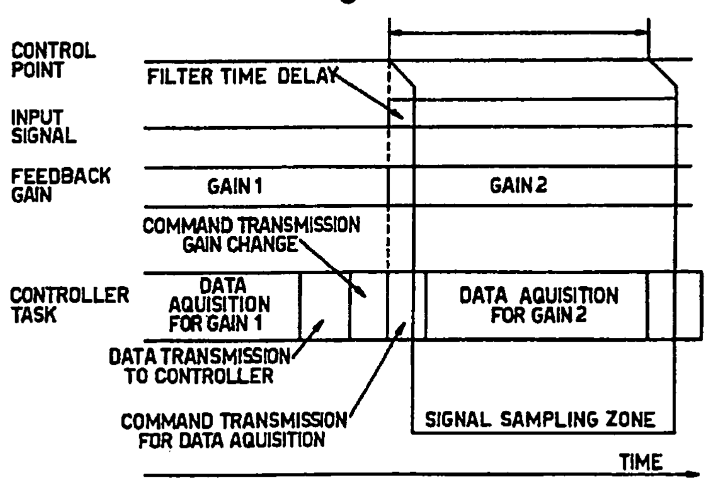
ONLINE : WPI

(54) **Adaptive gain control**

(57) A method and apparatus to control the gain of a feedback control system for controlling a parameter sets a control gain value and monitors the magnitude of the parameter. A new gain value is calculated and set dependent upon any change in the monitored magnitude. The new gain value is maintained for a period long enough to allow the magnitude of the parameter to settle, and the monitoring and gain calculating steps repeated until an optimum condition is reached. Methods for determining the magnitude of gain changes and sampling periods are also disclosed.

The controlled system may be a noise or vibration reducing system in a vehicle.

Fig.6.



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At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

Fig.1.

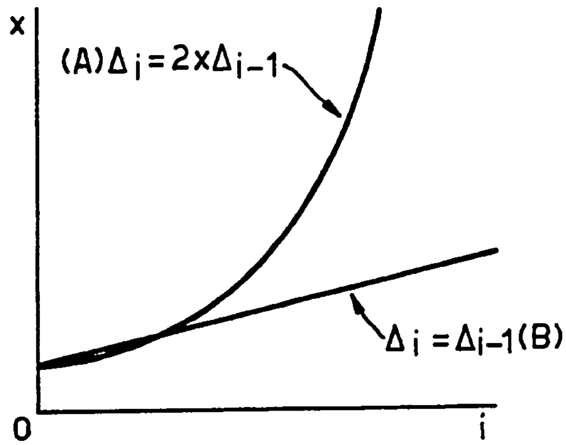


Fig.2.

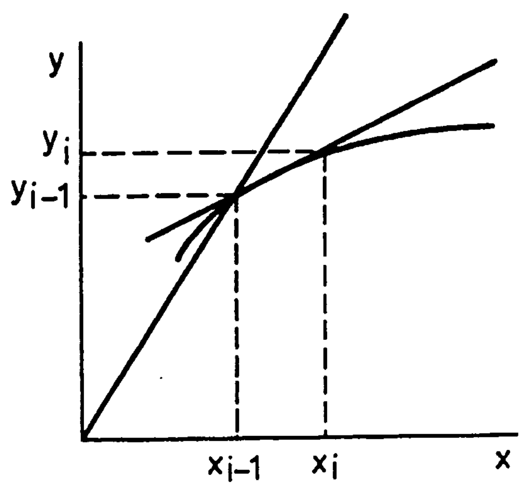


Fig.3.

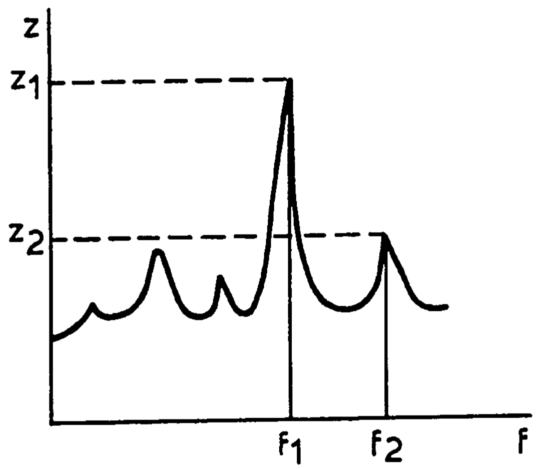


Fig.4.

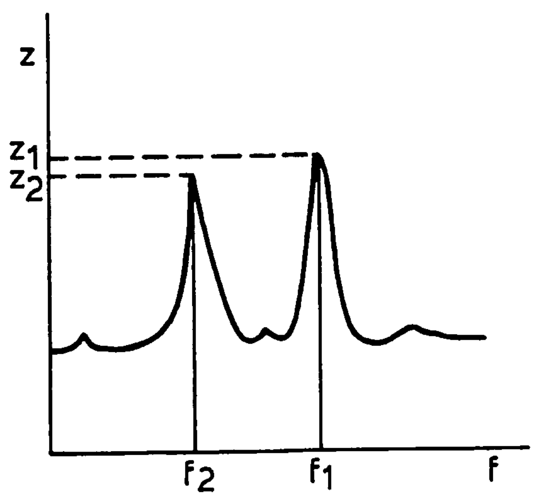


Fig.4A.

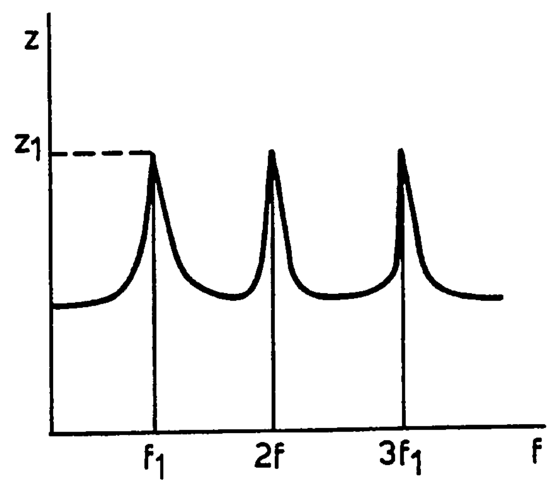
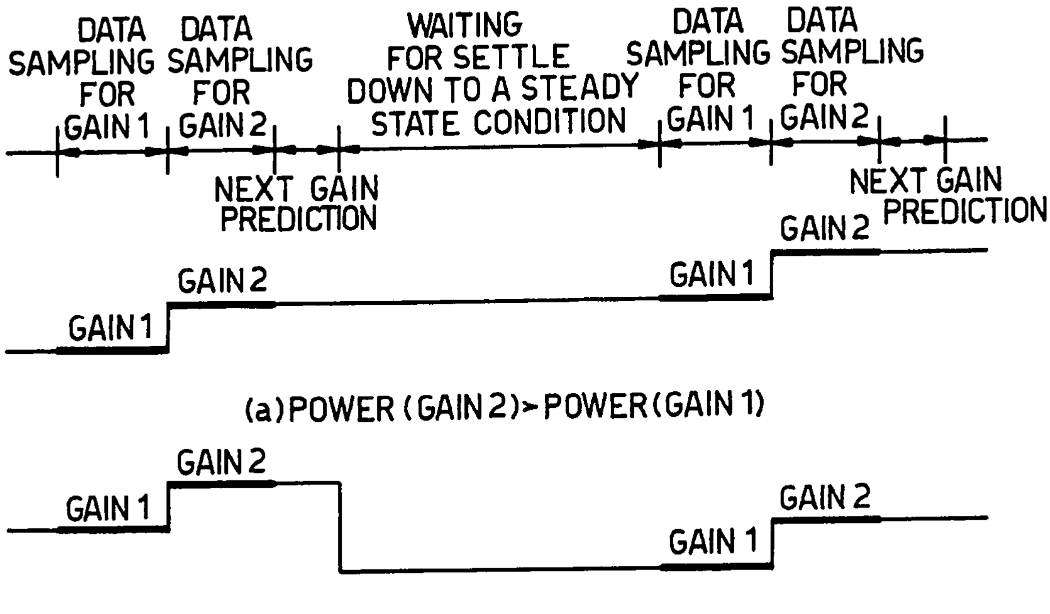


Fig.5.



(b) POWER (GAIN 1)< POWER (GAIN 2)

Fig.6.

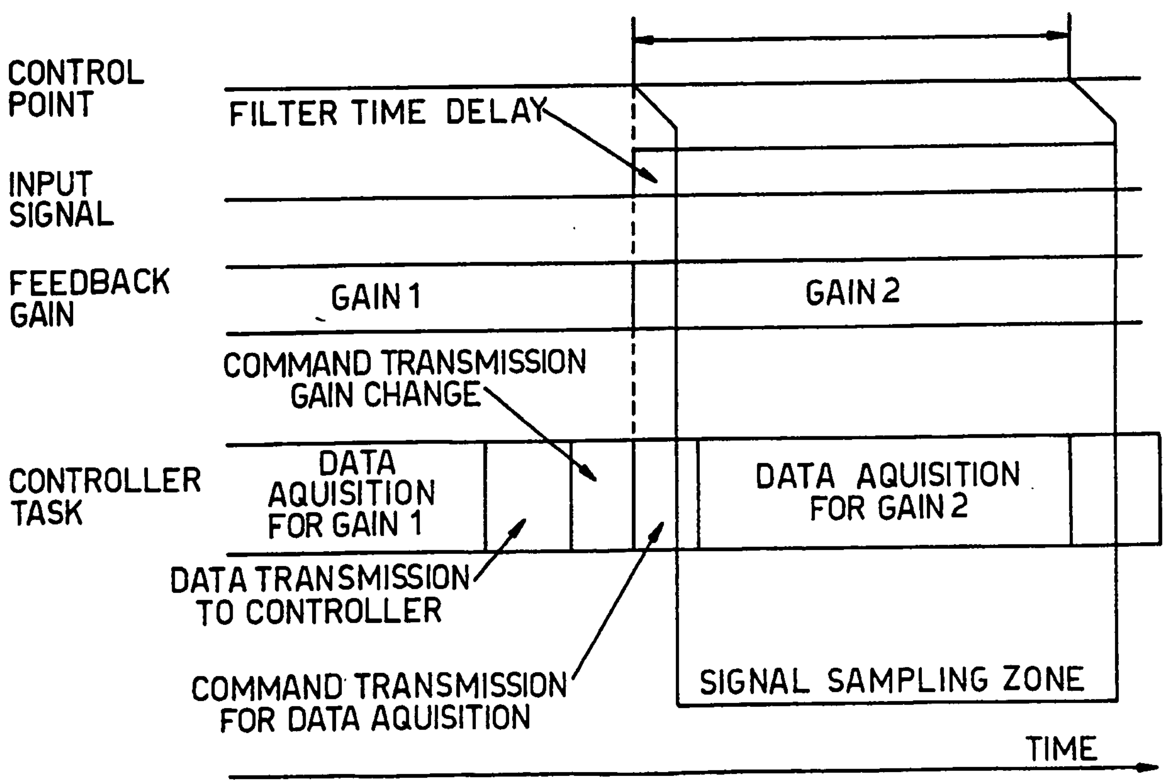


Fig.7.

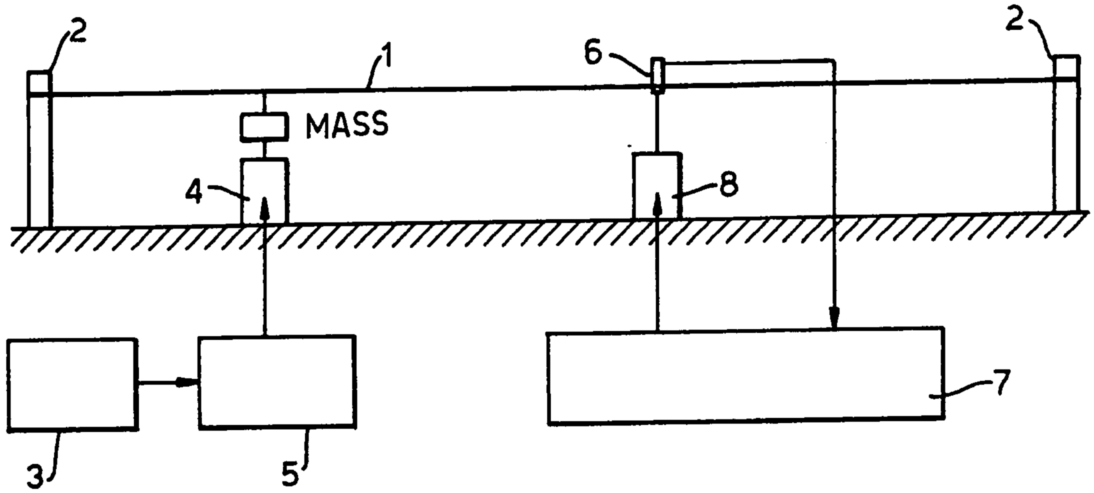


Fig.8.

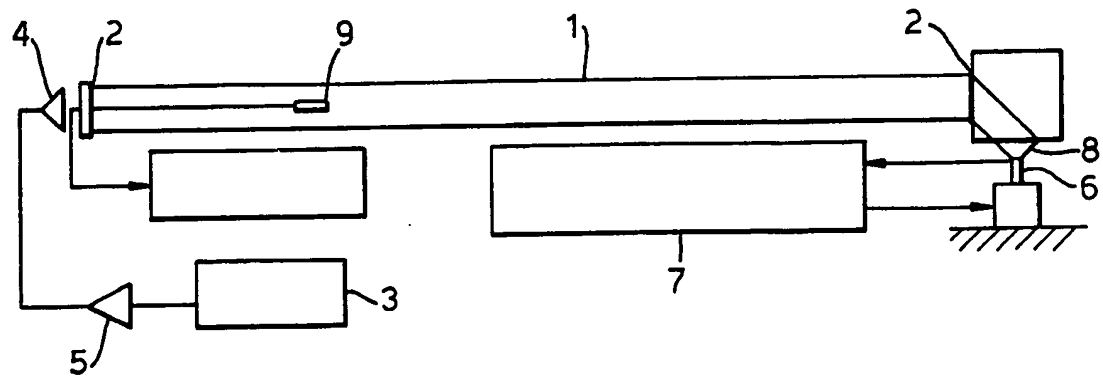


Fig.9.

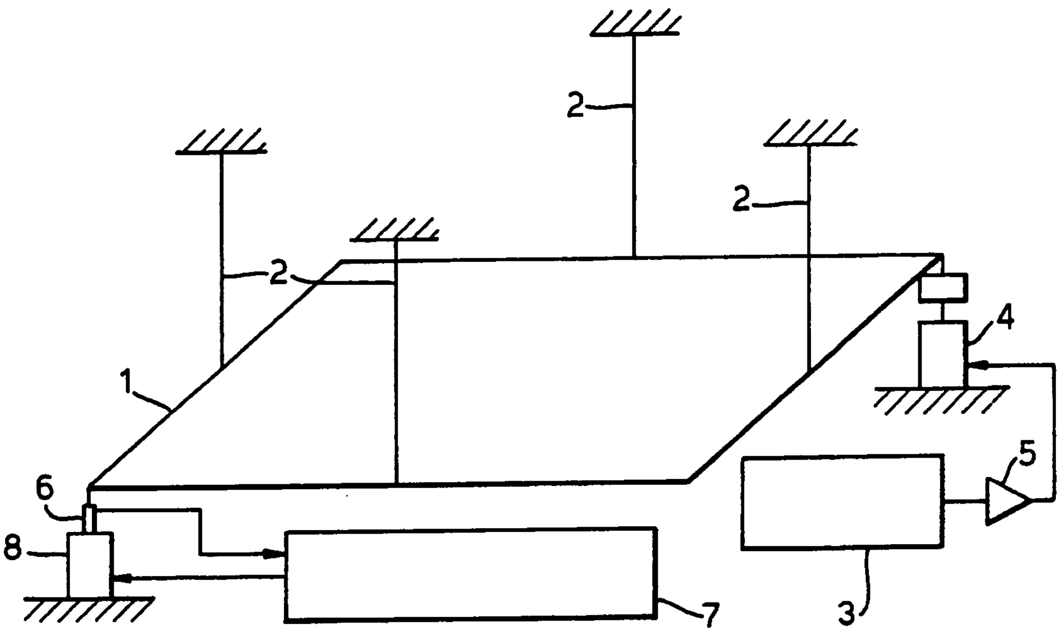


Fig.10.

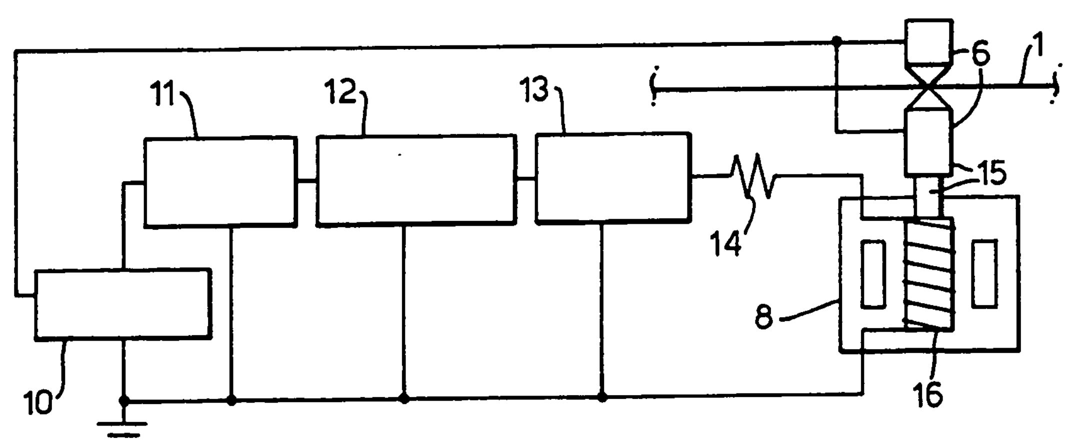
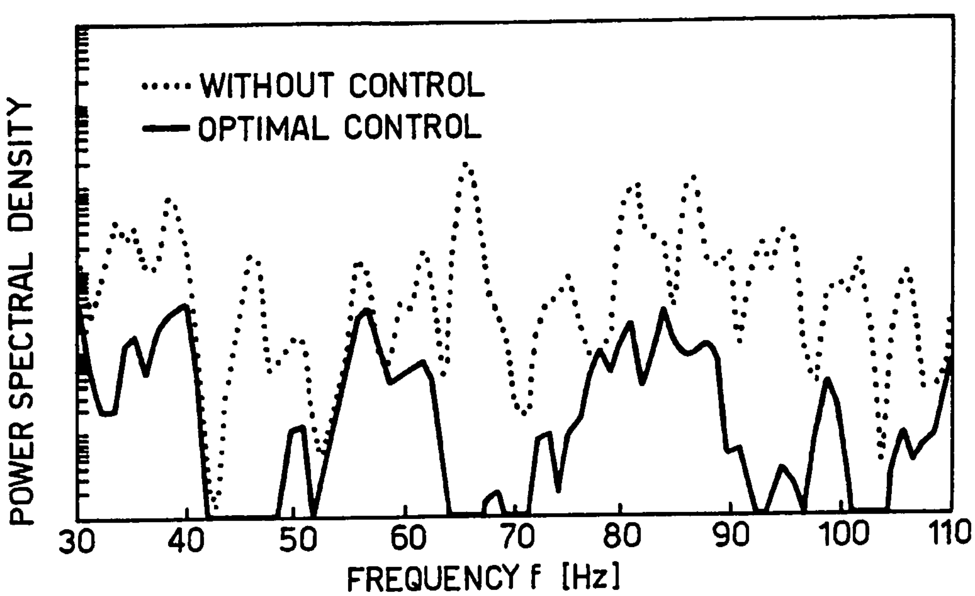


Fig.11.



WITHOUT CONTROL
OPTIMAL CONTROL
POWER SPECTRAL DENSITY
30
40
50
60
70
80
90
100
110
FREQUENCY f [Hz]

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IMPROVEMENTS IN ACTIVE CONTROL

This invention relates to active control systems. There are many situations where control of a system can be improved by actively controlling the feedback gain of its control system to provide an optimum output value. One particular example of a system in which such active control can provide more favourable results than traditional control systems is the field of vibration and noise suppression.

In order to improve efficiency and reduce manufacturing costs of vehicles and machinery there has, in recent years, been a requirement for the use of lightweight materials and an overall reduction in vehicle/machinery frame weight. Such weight reduction is not without its problems, in that greater vibration of frame components occurs. Such vibration can be suppressed by the introduction of vibration absorbing dynamic damper comprising a mass and a spring, but this often defeats the object of weight reduction. In order to overcome this problem there have been a number of proposals to provide feedback control systems which monitor vibration velocity and, via vibration generating "shakers", absorb the vibration.

In the control of noise, it has also been proposed to employ feedback or feedforward controlled anti-noise generating speakers. Such systems are limited by the constraints of the sensors required and the control system itself.

It would clearly be an advantage to use active control in such systems, but the active control must not introduce instability into the system and should be designed not to be system specific, so that it may be employed in a wide range of systems.

An object of the present invention is to overcome the above problems and provide an active control system that is stable and has a fast response time. A further object is

to provide a system which can actively control the vibration or noise in a system, but which can readily be adapted for use in a wide range of systems.

According to a first aspect of the present invention there is provided a method of controlling the gain of a feedback control system for controlling a parameter, the method comprising the steps of:

(i) setting a control gain value;

(ii) monitoring the magnitude of the parameter;

(iii) calculating and setting a new gain value dependent upon any change in the monitored magnitude;

(iv) maintaining the new gain value for a period long enough to allow the magnitude of the parameter to settle; and

(v) repeating steps (ii) to (iv) until an optimum condition is reached.

Additional steps may be included which provide for the case when the initial gain value is far too high and a calculation of the requirement for a large reduction in gain is obtained, i.e., when a decrease in the parameter is measured. In such a case, the method may comprise the step of reducing the gain by a predetermined factor and then repeating the monitoring, calculating and gain adjusting steps after the reduction has been made. The optimum condition may be a steady state.

The method may increment gain in a stepwise manner, calculating gain increment using the formula:

$$\Delta_i = \Delta_{i-1} \cdot \left(k_1 + \frac{k_2 (y_i - y_{i-1}) / (x_i - x_{i-1})}{y_{i-1}/x_{i-1}}\right)$$

where Δ_i is the gain increment, x is the gain, y is the parameter magnitude, k_1 and k_2 are predetermined constants, and Δ_{i-1} is the predetermined or previous gain increment.

Constants k_1 and k_2 can be altered to "tune" the formula to the system to which the method is applied, in many cases they will be set to 1.

With the above formula, an improved active control system with greater stability is provided. Such a method may be employed in the control of suppression of vibration and/or noise.

Active control systems are, generally, realised by digital devices such as microprocessors and the like. Such microprocessors require sampling of the system parameters in order to obtain values for processing. Problems occur in the determination of an optimum sampling period for such systems as the parameters to be monitored vary over time and at irregular frequency.

The present invention may also further comprise a method of determining a sampling period for the control system, the samplinig period determining method comprising the steps of:

determining the spectral density of the parameter power;

determining the frequency value and magnitude of peaks in the spectral density; and,

if the peak of greatest magnitude has a magnitude that is a predetermined number of times greater than any of the other peaks, setting the sampling period to two divided by the frequency value of the maximum peak or a multiple thereof, if the magnitude of a maximum peak is less than the predetermined number of times greater than the magnitude of the second largest peak, setting the sampling period to two divided by the beat frequency of the two peaks of greatest magnitude or a multiple thereof, and, if there are a plurality of peaks of similar magnitude, each separated from an adjacent peak by a substantially identical frequency value, setting the sampling period to two divided by the substantially identical frequency value or a multiple thereof.

Such a method, particularly if the predetermined number is approximately ten, provides a sampling period that enables stable but responsive control to be achieved.

Such a method can readily be employed in the active control of vibration and noise suppression.

One problem with existing active control systems is that they may operate to alter a gain before the true effect of the previous gain has been realised and therefore prohibit the system from reaching optimum conditions.

In order to overcome this problem, a third aspect of the present invention provides a method of actively controlling a parameter, the method comprising the steps of:

setting a first control gain value;

monitoring the magnitude of the parameter;

setting a second control gain value;

monitoring the resulting changed magnitude of the parameter;

calculating and setting a new first gain value dependent upon the monitored changed magnitude;

maintaining the new first gain value for a period long enough to allow the magnitude of the parameter to settle;

calculating a new second gain value dependent upon the new first gain value; and,

repeating the above steps until an optimum condition is reached.

The magnitude monitoring may consist of sampling the magnitudes several times in order to produce more accurate magnitude value data.

With the abovementioned methods, a particularly effective parameter to measure for the control of vibration or noise is vibration power or noise power. Using power as a control parameter makes the control far less system dependent and therefore more flexible to implement. The sensing and control of power by absorption is also far simpler to implement than the traditional monitoring and control of velocity. Preferably, vibration or noise acceleration is also monitored and fed back, in order to provide an improved active control system that has a better response. Alternatively, displacement could be measured.

Examples of the present invention will now be described with reference to the accompanying drawings, in which:-

Fig. 1 is a graph showing the change in gain versus the number of iterations for two traditional iterative active control systems;

Fig. 2 is a graph showing the magnitude of a control parameter in response to the changes in gain when the method of the present invention is employed;

Figs. 3, 4 and 4A are graphs showing three types of parameter frequency spectra encountered in active control;

Figs. 5 and 6 are timing diagrams for the method of the present invention;

Figs. 7 to 9 are schematic diagrams showing examples of how the method of the present invention can be employed in practice;

Fig. 10 is a schematic diagram of a shaker control unit as employed in the devices of figures 7 and 9; and

Fig. 11 is a graph showing the effect of a control system employing the methods of the present invention on a vibrating plate.

Fig. 1 is a graph with linear axes showing the change in gain versus the number of iterations i for two traditional ways of increasing gain in an active control system. The first of these (A) is to double the gain for each iteration. This provides a rapid response, but is unstable and liable to overshoot. The alternative approach (B) is to step up the gain by adding a fixed value to its magnitude on each iteration. Whilst this approach avoids the overshoot and stability problems of the first approach, it can lead to a very slow response time if a relatively large gain is required.

Fig. 2 is a graph of system parameter magnitude versus gain showing how a system employing a method of the present invention increases gain. A relatively low value of gain x_{i-1} is chosen as a starting value. The magnitude y_{i-1} of the parameter to be controlled is then monitored and

recorded. A small increase in the gain to a second value x_i is made by adding initial gain x_i to an initial gain increase step Δ_{i-1} and a second value y_i for parameter magnitude is measured. Using the formula

$$\Delta_i = \Delta_{i-1} \cdot \left(k_1 + \frac{k_2 (y_i - y_{i-1}) / (x_i - x_{i-1})}{y_{i-1}/x_{i-1}}\right)$$

a value Δ_i for the gain increase step is calculated, and the gain increased accordingly. k_1 and k_2 are predetermined constants that, in this example, are both set to 1, but each may be set to other values in order to provide the best control for the system being controlled. The gain increase step Δ_{i-1} is set at an initial value for a first iteration, but a previous iteration's value for the gain increase step is used for later iterations. The process can be repeated until an optimum condition (such as steady state) is reached.

As can be seen from Fig. 2, the method of the present invention provides for large steps in gain x when the parameter is increasing rapidly at low values of parameter magnitude y, but allows only small increases in gain x for larger parameter magnitudes and when the increase in parameter magnitude is not as large. This provides the high response time of the prior art doubling gain method, but reduces the degree of overshoot by operating in a similar fashion to the prior art incremental gain increase method at higher values.

It is possible that, for certain situations, the initial value of gain will be greater than that required by the system. In this case, the calculated value of gain increase will be less than the previous gain multiplied by k_1 and indicates this and the initial gain is then divided by a predetermined value, (in this example ten) and a further attempt at gain increase made. If the calculated value of gain increase still indicates that the initial

gain is too large, this step can be repeated. Examples of systems employing this method are described later.

Figs. 3, 4, 4A are graphs showing typical frequency spectra for vibration or noise power in a system. In all three, the magnitude z of a power is plotted against the frequency z at which the power level occurs, so that an indication how the power magnitude z is distributed over the frequency range can be determined. Fig. 3 shows an example where a single frequency value is dominant, and Fig. 4 shows an example where two frequency values are dominant. Fig. 4A shows a further example in which a single frequency and its overtones (multiples) are dominant, this case is particularly common for engine generated noise or vibration. In these examples, as the frequency range of power is large, it is difficult to determine the optimum sampling period that should be used if digital control is to be employed.

In the method of the present invention, the power is monitored for a short period and Fourier analysis is performed on it to produce a frequency spectrum. The frequency and magnitude of peaks in the generated spectrum are then recorded. Comparison of the magnitude of the peaks is then performed to determine whether or not any of the peaks are of at least the prescribed number (in this case 10) times greater in magnitude than the highest of the rest. If one of the peaks is this much greater in magnitude, its frequency value is noted and the optimum sampling period is set at 2 divided by that frequency. If, however, no peak is of a magnitude 10 times greater than any of the others, the two peaks of greatest magnitude are taken, and their beat frequency value determined by taking the magnitude of the higher frequency value and subtracting the lower frequency value. This beat frequency value is then used to set the sampling period at 2 divided by its value. A further alternative is that of figure 4A, in which a single fundamental frequency and its multiples are dominant, in this case, the fundamental frequency value is

taken and the sampling period set to 2 divided by the fundamental frequency value. With all three alternatives, the sampling period may be set at a multiple of 2 divided by the selected frequency if greater sampling accuracy is required.

Employing this method provides a sampling period which is short enough to provide an accurate representation of the power and its fluctuations without making sampling unnecessarily rapid. Again, examples of systems employing this method are described later.

Figures 5 and 6 are timing diagrams for a controller employing the method according to the present invention. The sample sets a first gain, gain 1, and samples parameter data for this gain value. The system gain is then set to a second, slightly higher, gain 2 and a second set of data is sampled. For both the first and second data samples more than one data sample may be taken at intervals and an average obtained in order to reduce the effects of noise. Using the two sets of data, the controller determines whether the gain should be increased, reduced, or stay the same and the gain is altered accordingly. An algorithm of the type previously described may be used for this gain increase calculation, although it is possible to use one of the above prior art algorithms in its place. Prior to setting a new gain value, the controller waits for a settle down period, so that later parameter measurements are not adversely effected by earlier changes in gain. Figure 6 shows how the controller operates in the gain setting and gain changing period between the settling periods. From this figure it can be seen that there is transition period between the two gain levels in which it is preferable to avoid data acquisition as spurious results could occur. If a signal filter is employed and the signal to a data collector is delayed for a period longer than the signal filter delay, this may, in itself, introduce the necessary delay as well as filtering out noise.

Examples of three systems employing the above methods will now be described with reference to figures 7 to 10. Figure 7 shows a string 1 attached at both ends to supports 2. Vibrations are generated in the string 1 by a signal generator 3 coupled to a shaker 4 via a power amplifier 5. The force and velocity of the vibrations are measured by a sensor 6 and fed to a controller 7 which calculates the power of the vibrations. The controller 7 may be set with a standard sampling period, or may, alternatively, employ the method of the second aspect of the present invention to calculate a sampling period. The controller 7 may employ either of or both of the first and third aspect methods of the present invention to produce a feedback control system of the velocity, acceleration, or power type to control a control shaker 8. The control shaker 8 generates vibrations which absorb those generated by the shaker 4 and vibrational power is actively absorbed. It will be appreciated that this control system can be readily adapted to systems other than a simple string, such as components in a motor vehicle, machine tools, offshore structures, spacecraft etc. In a motor vehicle, the vibrations will be generated by the engine, uneven road surfaces, and similar sources. By the employment of a single sensor unit and shaker attached to the component for which vibration is to be controlled, in combination with a control unit, the vibration can be controlled. As mentioned previously, effectiveness of the control can be improved by measuring and feeding back the acceleration of the vibration in addition to force and velocity. As acceleration is simply the differential of velocity, this can be calculated without the need for additional sensors and at little extra component cost.

Figure 8 shows how a control system employing the methods of the present invention can be employed in noise suppression. Components with functions corresponding to those in the device of figure 7 are identically numbered. In this case, sound is generated by a speaker 4 and

cancelled out by a control speaker 8. In this case the sensor 6 may be a microphone or electro-acoustic transducer. Again, power rather than velocity is a preferable control parameter as it provides improved control characteristics. An air filled pipe 1 is the equivalent of the string 1 of figure 7. To maintain the system effectiveness a microphone 9 was inserted to indicate the degree to which sound has been reduced by the active controller 7.

Figure 9 shows an example of a controller employing the methods of the present invention used to control the vibration in a plate 1. Again, components with functions identical to those of components in figure 7 are identically numbered. In this case the plate 1 is supported by wires 2, but the shakers 4 and 8 are identical to those in Figure 7. Experiments have shown that the controller 7 operates equally as well in a plate system as it does in a simple string. Figure 11 shows the positive effect on power spectral density of vibration at the control point that the system has on the plate 1.

Figure 10 is a block diagram of the components of the controller 7 and shaker 8 employed in the systems of figures 7 and 9. The output of the sensor 6 is fed to a sensor 10 and fed to a calculating unit 11. The calculating unit 11 determines the necessary gain increment using the velocity and force readings from the sensor 6 by employing one or more of the methods described above and feeds a gain value to an amplifier controller 12. The amplifier controller 12 controls a power amplifier 13, which is fed through an optional resistor 14 to the control shaker 8. The optional resistor 14 reduces the damping in the control shaker 8 by reducing the back EMF generated by vibrations in the string/plate 1 moving a shaft 15 through a coil 16 in the control shaker 8. The control system may switch in the resistor 14 to the circuit if it determines that the damping inherent in the control shaker 8 is too great to allow active control to be performed. This would

allow higher damping for high impedance vibrations and reduced damping for lower impedance vibrations. A similar resistor could be introduced in the control circuit of the speaker in the example of figure 8 if required.

CLAIMS

1. A method of controlling the gain of a feedback control system for controlling a parameter, the method comprising the steps of:

(i) setting a control gain value;

(ii) monitoring the magnitude of the parameter;

(iii) calculating and setting a new gain value dependent upon any change in the monitored magnitude;

(iv) maintaining the new gain value for a period long enough to allow the magnitude of the parameter to settle; and

(v) repeating steps (ii) to (iv) until an optimum condition is reached.

2. A method according to claim 1, further comprising the steps of:

setting a second control gain value after step (ii), and monitoring any resulting change in parameter magnitude; and;

calculating, after step (iv), a new second gain value dependent upon said new gain value.

3. A method according to claim 1 or 2, wherein new gain values are set by stepwise increments of previous gain values, the method further comprising the steps of:

setting a predetermined initial gain increment;

calculating a desired gain increment in accordance with the initial gain value and the magnitude of the parameter; and

setting the new gain value by adding the calculated gain increment to the initial gain value and setting the new calculated gain value as a new initial gain value.

4. A method according to claim 3, wherein the gain increment is calculated using the formula:

$$\Delta_i = \Delta_{i-1} \cdot \left(k_1 + \frac{k_2 (y_i - y_{i-1}) / (x_i - x_{i-1})}{y_{i-1}/x_{i-1}}\right)$$

where Δ_i is the gain increment, x is the gain, y is the parameter magnitude, k_1 and k_2 are predetermined constants, and Δ_{i-1} is the predetermined or previous gain increment.

5. A method according to any of the preceding claims, further comprising a method of determining a sampling period for the control system, the samplinig period determining method comprising the steps of:

determining the spectral density of the parameter power;

determining the frequency value and magnitude of peaks in the spectral density; and,

if the peak of greatest magnitude has a magnitude that is a predetermined number of times greater than any of the other peaks, setting the sampling period to two divided by the frequency value of the maximum peak or a multiple thereof, if the magnitude of a maximum peak is less than the predetermined number of times greater than the magnitude of the second largest peak, setting the sampling period to two divided by the beat frequency of the two peaks of greatest magnitude or a multiple thereof, and, if there are a plurality of peaks of similar magnitude, each separated from an adjacent peak by a substantially identical frequency value, setting the sampling period to two divided by the substantially identical frequency value or a multiple thereof.

6. An apparatus for controlling the gain of a feedback control system for controlling a parameter, the apparatus comprising:

means for setting a control gain value;

means for monitoring the magnitude of the parameter;

means for calculating and setting a new gain value dependent upon any change in the monitored magnitude;

means for maintaining the new gain value for a period long enough to allow the magnitude of the parameter to settle; and

means for operating the monitoring, calculating and maintaining means to reach an optimum condition.

7. A method substantially as described with reference to the accompanying drawings.

8. An apparatus substantially as described with reference to the accompanying drawings.

The Patent Office

-15-

Application No: GB 9510786.8
Claims searched: 1-6

Examiner: Mr Andrew Bartlett
Date of search: 24 July 1995

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.N): G3R (RBS,RBU,RAE,RAD); G3N (NGDB,NGE1,NGBB3); H4J (JGA)

Int Cl (Ed.6): G05B 13/02; G05D 19/02; G10K 11/16,175 & 178;

Other: ONLINE:- WPI

Documents considered to be relevant:

Category	Identity of document and relevant passage			Relevant to claims
X,Y	GB 2176029 A	(Kollmorgen Tech Corp)	See whole document	1,6 at least
X,Y	EP 0256842 A2	(Toshiba)	See whole document.	1,6 at least
X,Y	EP 0212840 A2	(Plessey)	See column 3 lines 23-24 in particular.	1,3 & 6 at least.
X,Y	US 4498036	(Salemka)	See whole document.	1,6 at least.
X,Y	Electrical Review Volume 222 No. 11, 31 May-13 June 1989, Caterina Gionata, "Adjusting to Self-tuning" pages 16-18.			1,3 & 6 at least.

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
		E	Patent document published on or after, but with priority date earlier than, the filing date of this application.
&	Member of the same patent family		